Augmented Reality-based Exergames for Rehabilitation

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ABSTRACT

Rehabilitation for stroke afflicted patients, through exercises tailored for individual needs, aims at relearning basic motor skills, especially in the extremities. Rehabilitation through Augmented Reality (AR) based games engage and motivate patients to perform exercises which, otherwise, maybe boring and monotonic. Also, mirror therapy allows users to observe one's own movements in the game providing them with good visual feedback. This paper presents an augmented reality based system for rehabilitation by playing four interactive, cognitive and fun *Exergames* (exercise and gaming).

The system uses low-cost RGB-D cameras such as Microsoft Kinect V2 to capture and generate 3D model of the person by extracting him/her from the entire captured data and immersing it in different interactive virtual environments. Animation based limb movement enhancement along with cognitive aspects incorporated in the game can help in positive reinforcement, progressive challenges and motion improvement. Recording module of the toolkit allows future reference and facilitates feedback from the physician. 10 able-bodied users, 2 psychological experts and 2 Physical Medicine and Rehabilitation physicians evaluated the user experience and usability aspects of the exergames. Results obtained shows the games to be fun and realistic, and at the same time engaging and motivating for performing exercises.

CCS Concepts

•Computing methodologies → Mixed / augmented reality; •Applied computing → Interactive learning environments; •Software and its engineering → *Interactive games;* **•Information systems →** *Multimedia information systems;*

1. INTRODUCTION

According to the Center for Disease Control and Prevention (CDC), approximately 800,000 people suffer from stroke every year in the United States [1]. About 130,000 of them die every year, making stroke the fifth leading cause of death [1] and the leading cause for serious long term disability [1]. Interruption in the normal flow of blood or bleeding in the brain, damage the brain cells that start dying within minutes leading to a condition known as Stroke. Damage to the brain cells triggers symptoms in parts of the body they controlled, attention deficiency, long-term disability, weakness and partial paralysis on localized regions or even death[2]. Usually patients suffer from post-stroke impairments, which result in loss of ability to carry out normal daily tasks. Approximately 80% of the stroke survivors suffer from upper limb impairments [2]. More than 40% of the patients receiving lower limb rehabilitation therapy sessions are not able to walk freely even after completing therapy [18].

Rehabilitation for patients affected by stroke involves motion recovery of the affected body parts, mainly extremities, through intense, skillful training exercises. Various strategies for rehabilitation [9] include physical tasks such as reaching, flexing and grasping objects of daily use (e.g., coffee cup, phone, TV remote, ball, etc.) for upper limb enhancement. Lower limb rehabilitation involves task specific therapy such as treadmill training with partial support of body weight, hip and knee extension exercises. Through repetitive exercising under therapist supervision, the areas of the brain affected by stroke get stimulated. Over a period of time, this can result in relearning the basic movements [2]. Action observation of performed tasks through videos, images or even live stream improves the movement recovery significantly [30]. In recent years, Exergaming (exercise and gaming) [32], also known as Serious Gaming, has emerged as a cost effective rehabilitation tool [29], making repetitive exercising a fun and motivating task.

One way of improving motion recovery using action observation suggested in [30, 26, 13] is the use of Augmented Reality (AR). Most of the AR systems proposed in the literature for rehabilitation exercises need external devices or sensors to be worn by a person. This is invasive in the sense that it inhibits the normal user movements making them uncomfortable [3, 5, 6, 10, 34], and hence cannot be used for in-home rehab. Non-invasive systems proposed in [15, 31] use webcams to capture the person which is in 2D and hence needs another device to track the hand movements in 3D. Having various different devices not only makes the system limited to complex laboratory setup, but also bumps up the overall cost. Virtual avatars have been used in some of the systems to replicate the human movements. With the advent of low-cost 3D cameras, it has become possible to capture "live" human models/avatars and immerse them in

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AR games. This approach is non-invasive in the sense that no additional sensors need to be worn by a patient. Also, using such live human models/avatars helps in understanding the emotional experience of the persons carrying out the exergames. The challenge here is that obtaining, generating, and rendering 3D mesh models of the human present in the scene needs to be done in real-time. Along with this task of 3D model capturing and rendering, a nice augmented environmental setup is needed in order to make the exercising task fun, engaging and non-monotonous.

1.1 Proposed System

The proposed architecture uses Microsoft Kinect V2 [8], a low-cost and off the shelf depth sensing, non-invasive, markerless camera, to capture the entire scene in real-time. Apart from RGB and depth streams, Kinect V2 also provides a skeletal stream that provides the movements of the human body joints' movements in 3D space. This skeletal data stream is used to perform physically based interactions. The captured 3D human model is placed into an AR scene for exercising by playing games using Mirror therapy [33, 35]. Animation based virtual enhancement is carried out on the limbs to provide positive reinforcement and motivation to perform tasks in the AR space that are not possible in the real world. Based on this approach, a toolkit consisting of 4 immersive exergames is made available for post-stroke rehabilitation. The toolkit also contains additional features for game selection, session recording, and playback (for future reference and expert feedback), and user mode selection (physician vs. patient). The four immersive games in the toolkit - ShotPut, Bowling, Balance, and RehabQuiz - target different rehab exercises, namely Elbow Flexion, Elbow Extension, Elbow Rotation and Hip Abduction. Along with the physical task being performed, the RehabQuiz game incorporates a cognitive aspect by including general knowledge questions to be answered.

1.2 Contributions

The proposed exergaming system was tested and evaluated by 10 people with no known disabilities, 2 psychology experts and 2 Physical Medicine and Rehab physicians. In this paper, we make the following contributions:

- Cost effective, easy to use, non-invasive system for live 3D capture of a person and its use in various augmented reality settings.
- Mirrored view of participants help understand their emotional experience during the game-play, especially for physicians reviewing the recorded game sessions.
- Use of animation based virtual enhancement performed on the skeletal joints as well as mirror therapy to assist patient rehabilitation.
- The feedback from the 2 Physical Medicine and Rehab physicians and the 2 psychology experts shows that the augmented reality based exergaming system is enjoyable, engaging, assistive and motivating, having good potential in rehabilitation for stroke affected patients.

2. RELATED WORK

Serious games for rehabilitation are designed by keeping in mind that they should: (a) be fun to play; (b) have a level of uncertainty in output; (c) be accompanied by awareness of a virtual reality [4]. Essential components of effective stroke rehabilitation therapy, as mentioned in [20], include:

- Adaptability to motor skill level, meaningful tasks, appropriate feedback, theory appropriate range of motion, focus diversion from exercise, intentional movement and quantitative measures.
- Include criteria such as personalization, ease of use, intuitive interface, default mode settings and efficient setup.
- Provide appropriate challenge, motivational feedback, easy availability, and affordability.
- Immerse the person in the virtual scene at a sufficiently fast rate so as to have a good, smooth and lag-free rendering.

Mirror therapy [33, 35] is the use of the mirrors to reflect the non-paretic arm movements to make the affected hand function as if it were normal. It has been proved that mirror therapy improves the hand functioning more than general rehabilitation as shown in [35]. Two groups took part in the experiments: one just performed the task and the other group people, before performing the actual task, went through 30 minute session of observing their own non-paretic hand movements through a mirror giving them an illusion of a virtual hand performing the same movement tasks. The group that used mirror therapy performed better in the normal tasks and proved that such illusion or virtual enhancement can be used to facilitate and speed the rehabilitation. Augmented Reality Technology (ART) system proposed in [23] is able to manipulate the experience of reality around the aspects of belief, interactivity, predictability and decoupling and demonstrates the potential of AR to improve health and well-being.

In lower limb rehab, robot based technologies along with treadmill training with body weight support are used for repetitive locomotive gait rehabilitation with a special focus on children with cerebral palsy [7, 16, 19]. A VR-based soccer scenario was developed to provide interactive elements to engage patients during robot assisted treadmill training [3]. The study used 18 children who were asked to walk on the Lokomat, which is equipped with sensors at hip and knee joints. The study showed that the use of VR scenario induced an immediate effect on motor output thereby helping in gait rehabilitation.

Over the past few years, various attempts have been made at developing serious games by using robotic/haptic controls along with commercial games as well as standalone console games created for specific rehabilitation tasks. Because these games are considered fun, patients are more likely to engage in the activities and this may lead to improved sustainability of exercise routines. Robot based rehabilitation is used for reducing the expert therapist involvement and provide for mass repetitive training. Some robotic devices for upper limb rehabilitation include MIT-MANUS [17], Bi-Manu Track [14] and T-WREX [25]. Such systems motivate the patients to perform repetitive tasks by making it easy and forcefully assistive, but at the same time the invasive nature, cost and lab setup requirements make it unsuitable for in-home rehab. Use of various commercial cameras such as Sony EyeToy, Nintendo Wii, OptiTrack, Microsoft Kinect

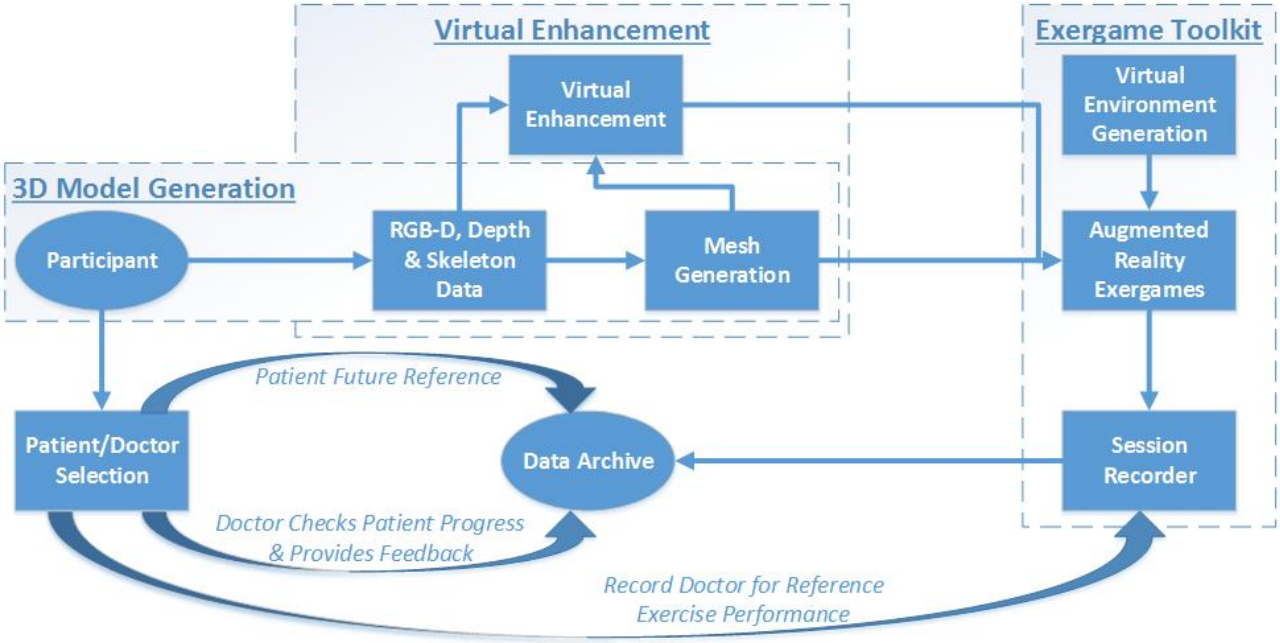


Figure 1: System schematic showing the major modules: 3D model Generation, Exergame Toolkit and Virtual Enhancement.

and other webcams have increased to generate augmented reality setups for rehab by capturing and imitating user movements. Such off the shelf cameras make the game creation and deployment easy and affordable, and hence have recently gained much interest in physical therapies. Apart from Kinect, almost all other commercial camera setups require additional invasive procedures for the 3D capture.

Sony PlayStation 2 EyeToy is used in [22] to generate a video-capture VR platform for creating games but needs people to stand and play, making it inconvenient for those having balance impairments to perform exercises. TheraMem system showed in [24], "fools the brain" by visually amplifying users' hand movements - small actual hand movements lead to perceived larger movements. The results from forty-five non-clinical participants validate the system but it is specifically for hand and finger movements. Gesture Therapy system showed in [31] provides a very cheap alternative by using webcams for capture and interact with virtual games by performing arm movement exercises. The use of webcam in rehabilitation restricts the movement in 2D plane and hence needs an additional gripper having a colored ball to track the 3D arm position. Use of such system needs the stroke patient to have the ability to hold the ball without occlusion and the 3D movement is also restricted. Theragame[15] is a really cost efficient and easy to use VR system using a single webcam to perform in-home rehabilitation. However, it is not able to capture the 3D motion making it ineffective for general rehab.

3D infrared passive motion capture system in [10] uses 10 cameras for recording the user movements. Reflective markers are placed on the body, such as hand, arm, shoulder and trunk so as to get their positions in 3D space. Participants sat on a table and performed reaching movements towards real objects as well as virtual objects, with guidance from visual and audio feedback in the large display in front. Major cons for using such a setup for in-home therapy include high cost and size of the system as well as the need of wearing extra markers on the body. Games are developed using Kinect for non-invasive tasks such as EEG-based functional brain mapping as shown in [27]. A Kinect based motor rehabilitation system is developed and evaluated in [12]. The system is shows an exergame with support for multiple biomechanical movements along with analysis and postural compensation. This prototype system performs well on the evaluated healthy users but does not provide any assistive feedback in terms of virtual enhancement. A single Microsoft Kinect, is used by [11] in creating a duck punching game to perform reaching tasks by punching the virtual duck targets placed in different virtual environments. The movement of the patient is emulated using a virtual arm that can be enhanced in a controlled manner. The game tracked the 3D location and showed the virtual arm but lacked the complete visual aspect of showing the real person in the game.

OptiTrack system consisting of 8 near infrared cameras is used in [5, 6, 34] to capture and track the reflective wristband worn by the person. Based on the tracked location and the pressure feedback obtained from the chair and the table, correct movement of the person is obtained. Both audio and visual feedbacks are provided by the system during rehabilitation. The OptiTrack system is not as expensive as [10] but it needs expert knowledge for set up and use. Also, it is invasive, needing the person to wear reflective markers on the affected limbs, and it is not easy to deploy for in-home rehab.

3. PROPOSED SYSTEM DESIGN & ARCHITECTURE

The proposed system consists of 3 major parts, as shown in Figure 1: (i) Human 3D model generation; (ii) Augmented reality toolkit for exergames; and (iii) Virtual enhancement. An exergame toolkit consisting of 4 augmented reality based games is developed as explained in section 3.1. The participant, a patient or a physician, needs to be placed in the AR scenario by capturing and generating a 3D mesh model as explained in section 3.2. Animation based virtual limb enhancement, section 3.3, is then incorporated along with the mirror therapy to assist with patient's movements in the AR space.

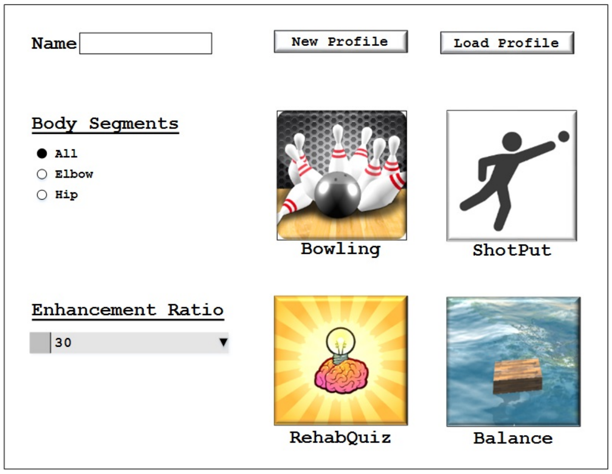


Figure 3: Exergaming toolkit, showing game selection based on body part, user profile creation/loading and enhancement ratio selection.

3.1 Exergame Toolkit

An easy to use interface is provided for browsing and selecting a game based on the name or the body joint that one wants to perform exercise on, e.g. elbow, hip, all, etc., as shown in Figure 3. User profiles can be created and saved so as to use them for future reference or for therapist/physician review. A drop down menu is provided for selecting the desired assistance ratio provided by the system in terms of virtual limb enhancement.

Different exercises that are showcased include Elbow Flexion, Elbow Extension, Elbow Rotation and Hip Abduction, as shown in Figure 2. The exercises mentioned are adapted from publicly available websites supervised or created by certified rehabilitation specialists - http://www.stroke-rehab.com/ & http://www.hep2go.com/. Based on the exercises, 4 different games having one-to-one correspondence to the exercises are developed - ShotPut (Figure 8) for Elbow Flexion (Figure 2a), Bowling (Figure 9) for Elbow Extension (Figure 2b), RehabQuiz (Figure 10) for Elbow Rotation (Figure 2c) and Balance (Figure 11) for Hip Abduction (Figure 2d). RehabQuiz not only makes the person perform the physical exercise, but also presents a focus on cognitive aspect to answer some basic set of general knowledge questions. In this toolkit, we facilitate exercises on lower part of the body i.e. hip abduction in Balance, which not many researchers have focused on.

A recording facility is provided with the system that will allow both physician and the patient to view the action performed for future reference and modifications. The live feed of the entire scene is recorded while the game is being played and a video is generated at the end of the game playing. This allows for session recording and a feedback for the physician to understand the correctness of performed motions as well as the patient's emotional experience. Although the game has a scoring method, the patient might not adhere to the correct motions exactly and hence, the video generated can act as an added check for correctness of movements. Along with the entire scene recording, a facility is provided for the physician to record the correct movements to be performed in each game that can act as reference for the patient. Figure 4 shows the system in which the physician can interactively select a game. After a countdown, the system allows the physician to perform 15 seconds of recording for the particular game selected. The recorded video of the physician can serve as a reference for the patient during in-home rehab.

All the games use the same underlying architecture: (a) person identification and tracking using Kinect; (b) physically based interaction with virtual objects; and (c) virtual limb movement enhancement. Virtual scoring is maintained to motivate people to compete with themselves for improving their skill in turn leading to improvement in their motor abilities. Different scene locations such as an Olympic stadium, an indoor bowling arena, beach and a closed room are put up so as to showcase the AR capabilities of the proposed toolkit as well as to increase the interest and fun aspect of the game. To incorporate action observation, an animation based model is used incorporating the virtual enhancement based motions, as explained in section 3.3.

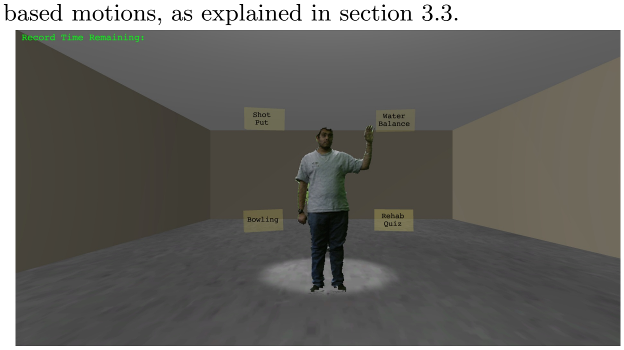
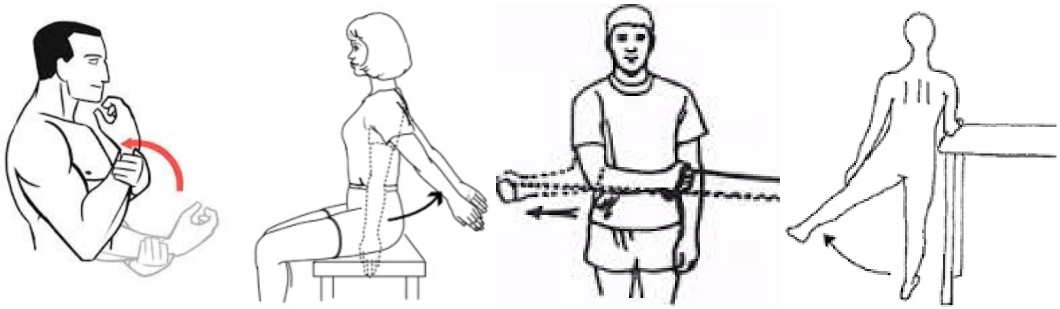


Figure 4: Recording system showing the person trying to record a game by selecting it.

3.2 3D Model Generation

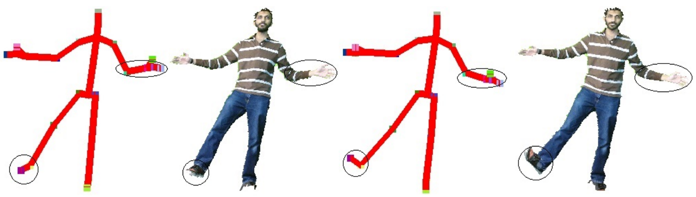
Kinect V2 is used to capture the scene and generate the 3D model of the person present in the scene. Depth and color are the major streams provided by Kinect. Random decision forest algorithm is run on the depth image to extract the features which are used in the estimation of skeletal limbs, as described in [28]. A human skeleton is fit on the extracted features to obtain a 25 joint skeleton model as shown in Figure 5a. Point cloud is obtained per frame using the depth image. Using the depth point cloud and the RGB image obtained from Kinect V2, a mesh is generated. Dense meshing strategy is used [21], which is a 2D meshing strategy that connects the neighboring vertices if their depth values are not significantly apart. Figure 5b shows one such mesh that is generated corresponding to the skeleton extracted.

The enhancement procedure (Section 3.3) works on the given skeleton information and generates a modified skeleton. Figure 5c shows one such case where enhancement is seen in the raised right leg as well as left arm. Rendering of the 3D model requires the mesh to be modified corresponding to the modified skeleton. An animation based enhancement strategy is incorporated as explained in [21]. Here, the enhanced skeleton, the original skeleton and the original mesh are used to generate the new enhanced mesh of the person, as shown in Figure 5d. The entire point cloud obtained is first segmented into different body part segments based on the skeletal joint using a Voronoi decomposition based approach. All the points present in each segment are transformed to a spherical co-ordinate system based on a control



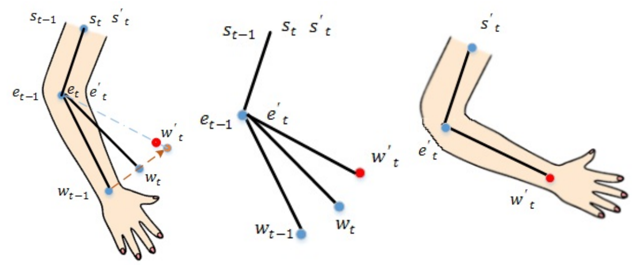
(a) (b) (c) (d)

Figure 2: Exercises used in games generated (a) Elbow Flexion (b) Elbow Extension (c) Elbow Rotation (d) Hip Abduction.



(a) (b) (c) (d)

Figure 5: Complete animation procedure with changes marked: (a) Original Skeleton as captured by Kinect (b) Mesh generated on the original skeleton and captured point cloud (c) Skeleton obtained after enhancement (d) Mesh animated using the original mesh, original skeleton and enhanced skeleton.



(a) (b) (c)

Figure 6: Illustration of enhancement for a simple wrist movement (a) pose of skeletal joints at time instance $t-1$ and t and enhancement estimation for wrist joint without normalization shown with orange point and (b) with normalization shown with red point and (c) enhanced pose obtained with the proposed method

point, i.e., the skeletal joint. For the enhanced skeleton, a new control point (skeletal joint) is used to place the spherical points in each segment back in the original Cartesian coordinate system. Merging all body segments yields the final animated model using the virtually enhanced skeleton.

3.3 Virtual Enhancement

For patients suffering from motor impairments, one of the major hindrances in improvement is the lack of motivation. Positive reinforcement accelerates the movement recovery during rehabilitation and can be provided by enhancing the motion of the paretic limb in the virtual world [11]. Using this concept, we propose an animation based virtual enhancement of the limb movements in which we animate the skeleton based on the previous skeleton by enhancing its movement.

In order to apply virtual enhancement on the skeleton, it is important to understand the direction and speed of the movement. Skeletal information is obtained in terms of 25 joints that are updated at a refresh rate of more than 30 frames per second. At any point in time, we maintain two skeleton structures: S_{t-1} and S_t. Displacement of any joint p is obtained using its position in skeleton at two time frames, p_t and p_{t-1}. Direction of displacement vector gives the direction for virtual enhancement. The magnitude of displacement, along with an enhancement factor determined by the therapist, decides the actual enhancement applied to the joint. For realistic enhancement, modification in any joint must also be applied to other joints connected to it, based on the local hierarchy of parent and child bones. We also provide two constraints for each bone describing a minimum angle and maximum angle of rotation between current bone and its parent bone. Though the proposed enhancement can be applied to any joint movement, we focus only on arm and leg.

Figure 6 illustrates the application of proposed virtual enhancement to wrist movement where w, e, s represent wrist, elbow and shoulder joints respectively. To enhance the wrist movement captured between the time instance $t-1$ and t, we compute a directional vector between w_t and w_{t-1} as illustrated in Figure 6, using the following equation:

$$|\vec{E}| = |\vec{d}| * E_f = |w_t - w_{t-1}| * E_f \tag{1}$$

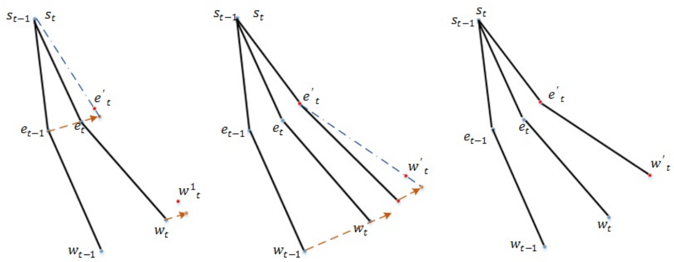
where $\vec{d}$ indicates movement displacement vector. Direction of $\vec{d}$ provides direction of enhancement $\vec{E}$. Magnitude of enhancement $|\vec{E}|$ is computed based on magnitude of $\vec{d}$ and E_f, the enhancement ratio determined by physician. We apply $\vec{E}$ on w_t to compute intermediate enhanced position of wrist w_i as indicated by orange dot in Figure 6. Direct application of $\vec{E}$ on w_t will result into unnatural elongation of bone. To resolve this issue, we normalize the current bone length between joint $e_t{}'$ and w_i by actual bone length by moving the estimated intermediate enhanced position of wrist joint in the direction $\overrightarrow{w_i e_t{}'}$ as follows:

$$\eta = 1 - \frac{|\overrightarrow{w_t e'_t}|}{|\overrightarrow{w_i e_t{}'}|} \tag{2}$$

$$w_t{}' = w_i - \eta \overrightarrow{w_i e_t{}'} \tag{3}$$

where η represents the normalization factor and $w_t{}'$ is final estimated enhanced position of wrist joint.

Consider a hierarchy for wrist, elbow and shoulder joint described by $w \in e \in s$ where $\in$ represent the relation "is child of". Movement in elbow will also move the wrist due



(a) (b) (c)

Figure 7: Illustration of enhancement of a complex movement involving multiple joints (a) Enhancement with normalization applied to elbow joint and its child join: wrist (b) Enhancement with normalization applied to wrist joint (c) Final enhanced pose

to the parent child relation. Figure 7 describes the complex motion involving movement of two joints: wrist and elbow. Ordering of the bones leads to enhancing the parent bone first and then proceeds down in the hierarchy. Hence, enhancement is first applied to elbow bone to obtain $e_t{}'$. The displacement computed while enhancing e_t is also applied to w_t to obtain ${w_t}^1$. Enhancement in w_t is computed based on displacement vector between w_t and w_{t-1}. Estimated enhancement is applied to ${w_t}^1$ to have accumulative enhancement at w_t.

4. EXERGAMES

Augmented reality based exergames for rehabilitation are designed and developed using Unity3D game engine. ShotPut, Bowling, RehabQuiz and Balance are the 4 exergames developed, each focusing on a different exercise. A simple strategy is employed: use close fist to grab an object and open fist to indicate release of an object. The open and close fist detection is performed using the Kinect V2 SDK. Each game consists of virtual instructions appearing on the screen. A scoring module calculates the score for a particular game and updates it on the screen to provide a sense of challenge. All games require the person to be standing or sitting in front of the camera, which is put right under the TV. Virtual enhancement is incorporated into the limb movements to assist and motivate the person and can be activated or deactivated at any moment during the game. The following subsections describe the unique characteristics of each game.

4.1 ShotPut

Elbow Flexion is the exercise performed to improve the motion of bending and straightening the elbow, as shown in Figure 2a. The game of *Shot Put* is selected and modified so that it would replicate the elbow flexion exercise. The game starts off by placing the person in the virtual scene consisting of a shot put arena made in an open stadium. The task is to throw the ball as far away as possible in the virtual world by taking the hand holding the ball as far back as possible and then bringing it forward and releasing the ball, making it travel in the direction of the motion with the velocity calculated using the change in the fist position with respect to the time taken. The further one can extend the arm, longer the distance the ball covers from the foul line and higher the score obtained. A virtual camera tracks and follows the ball once released. Figure 8 shows a person playing the game and gives a camera angle, when the ball is thrown and it lands on ground, along with score update based on distance from the foul line.

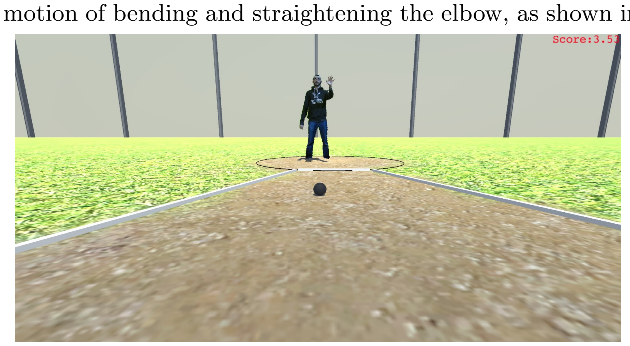


Figure 8: ShotPut game, associated with Elbow Flexion, showing a person throwing the 'shot' as far as possible based on which score for the 'put' is calculated.

4.2 Bowling

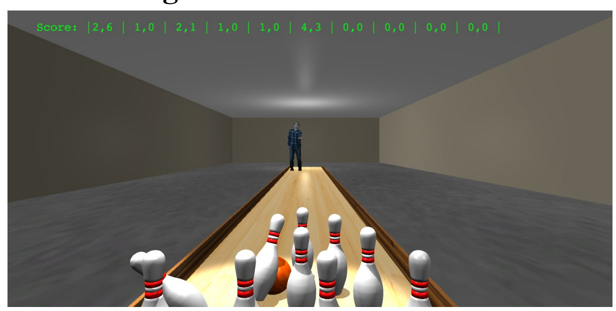


Figure 9: Elbow Extension exercise practiced by the person using Bowling game and getting the scores updated by hitting the pins.

Another important exercise for elbow rehabilitation is Elbow Extension. As shown in Figure 2b, the exercise involves keeping the elbow straight by stretching it out as far back as possible and bringing it in front. A virtual 10-pin *Bowling* alley, similar to the real game, is generated and the person is placed in it. The game starts with the person, either sitting or standing, and holding the ball normally on the side parallel to the body. The idea of the Elbow Extension exercise matches the concept of bowling which is to try and stretch the arm as far back as possible, bring it in front and release the ball by opening the fist to make it roll down the alley and hit the pins. Figure 9 shows one such situation where the ball is hitting the pins down. Based on the pins hit, a scoring mechanism as used in real bowling game is used to engage people and push them towards self-improvement. To allow for not getting demotivated by missing the targets, score for the current set starts only if there is at least one pin knocked down. For ease of use and motivation, the bowling alley is in-built with side extensions to stop the ball rolling into the gutter, pushing it back into the lane. Force and direction applied on the ball is based on the angle in which the person takes the ball back and releases it forward.

4.3 RehabQuiz

It maybe necessary to associate a cognitive aspect with the exergame, along with the physical aspects involved. We propose a trivia contest known as *RehabQuiz* to be performed along with Elbow Rotation (Figure 2c). Here, the participant places the elbow and the lower arm close to the body and rotates the elbow to make the hand go away from the body. A virtual room is set up in which the participant is

Figure 10: Person exercising Elbow Rotation in the RehabQuiz, a trivia game, showing him picking up a card form deck and answering the question.

placed sitting on a chair. A virtual table is shown in the game that has a deck of cards, each card having a question for the quiz, along with 3 bins where the cards are to be dropped. The person performs internal rotation of the elbow to bring the hand close to the card deck. S/he closes the fist to pick up a card, allowing a question to pop up, Figure 10. Depending on the answer to the question, s/he does external rotation of the elbow to go near the correct bin and drops the card by opening the fist. An appropriate message of wrong or correct is shown on table in front of the bins and the score is updated. The game engages the player in the quiz, while performing the elbow rotation exercise.

4.4 Balance

Figure 11: Balance game with person practicing Hip Abduction exercise by standing on 1 leg on water floating plank.

As mentioned earlier, lower limb rehab is important but majority of the rehabilitation exergames created using virtual reality focus on upper limbs. We propose *Balance*, a game with a specific focus on the lower limb, hip abduction exercise. Figure 2d shows a person performing the hip abduction exercise by standing on one leg and stretching in and out the other leg so as to flex the hip joint. A nice beach setup with a lighthouse and some trees is made so as to give a positive environmental feel. A wooden plank is placed on the water making it float and rotate when there is some unstable force applied to it. The game starts with the person standing on one leg, by default left, on the floating wooden plank. The person moves along with the plank simulating the scenario of person actually being present on it. Being a game of balance, the person is placed a bit away from the plank's center of gravity, making it unstable by applying some constant force on the plank in the direction of the person's center of mass. This creates an illusion of person losing balance and gradually falling into water. If the angle of the plank comes up to be too close to the water i.e. greater than 80 or less than 280, the person is virtually made to appear drown. To avoid getting virtually drowned, the person is motivated to move the right leg away from the body and perform hip abduction, Figure 11, shifting the center of mass of person to the left of the body and apply reverse force on plank, making the plank tilt in opposite direction. Time based scoring is performed by showing actual time duration one can stay on the plank without falling in water. Longer one stays on plank, higher is the score.

5. EXPERIMENTAL SETUP

Entire setup requires only one computer for processing, one display to see and enjoy the games and a single Microsoft Kinect V2 [8] for motion capture. The computer should be able to run graphics intensive application and thus should have a good graphics card, sufficient RAM and relatively new processor. The computer used in the experiment has a GTX 970 graphics card, Intel i7 2.4 GHz processor and 32 GB RAM. A Samsung 3D TV is used as the primary display. A single Microsoft Kinect V2 connected to the computer using a USB 3.0 is used to capture and extract the person present inside the scene. 3D model is generated on top of the captured information and transmitted at approximately 30 frames per second to provide real-time rendering. The entire motion capture and enhancement framework is written in C++ and the game development is done in Unity3D game engine using OpenGL rendering and PhysX for physics.

Normal, enhanced and restrained modes are designed for all the games. Balance game is played in only the normal game mode, where the person performs hip abduction exercise by standing at a particular location marked on floor. RehabQuiz game was calibrated to be played by sitting on a chair in front of camera (with change in calibration, it could also be played standing up). In the bowling game, people were allowed to stand or sit whichever was convenient with them. In both these games, RehabQuiz and Bowling, people played the game in normal as well as virtually enhanced mode. The game of ShotPut had one more specific restrained setup on top of both normal and enhanced mode. The restrained setup required the person to be tied up with chair using a bungee cord so as to restrict their arm movements. It was designed mainly to simulate the real world patient scenario and test the system on that. Figure 12 shows a person playing the ShotPut game with right arm tied to the back of chair so as to restrict ball releasing motion.

6. USER STUDY

A study was performed with a small group of able-bodied people to test the playability and the usability of the toolkit

Figure 12: Experimental setup showing a person playing ShotPut game with his right arm tied up with bungee cord to simulate patient condition.

Table 1: User study questionnaire & average scores for all games by 10 able-bodied people, 2 psychology experts and 2 physicians, using a 5 point Likert-type scale from -2 to 2.

Question	**Avg Score**
Overall experience	1
Visual quality - Game environment and person	1.46
Ease of use	1.26
Correctness - How correct does game replicate user motion	1.14
Likely to play again	1.12
Fun to play	1.22
Motivating to exercise by engaging in the game rather than the focus on exercise	1.38
Hard work - does it feel that you exercised enough	1.04
Enhancement Mode	-
Visual quality - Game environment and person	0.1
Improved performance	0.5
Restrained Setup	-
Simulates handicap situation	1.25
Difficult than normal	1.63
Improved performance by enhancement	1

in rehabilitation scenario. A total of 10 healthy adults, 2 psychology experts and 2 Physical Medicine and Rehab experts volunteered for the study. 8 of the participants were male and 6 were female. Age of the participating people was from 23 to 50 with the median age of 28 years. Out of them, 10 had experience in playing video games and 4 of them had an idea about using VR for serious games.

The research team initially explained the task required to be performed by giving out a demonstration for each game. Based on the handedness selection, right or left, situation of the game and their comfort level, people were asked to either stand or sit on a chair in front of a 60" 3D LED Smart TV. They were then asked to play the games one after other and fill out a questionnaire for each game. The questionnaire asked about different parameters used in the games, virtual environments used for immersion and exercise motivation for stroke patients. Most of the questions asked were objective so as to get a quantitative analysis. A number of subjective criticisms, both positive and negative, were also provided as qualitative analysis. Table 1 shows the set of questions asked for the games played. Answers had to follow the 5 point Likert-type scale, ranging from -2 being very bad to 2 being very good.

Based on results shown in Table 1, overall the exergames were considered favorably. From individual game results, almost everyone liked the Balance game better (perhaps, because no interaction was involved with virtual objects in terms of picking or dropping). People remarked that though the interaction with the virtual objects, such as ball or card is needed and performed relatively well, there were still scenarios where the Kinect could not detect the closed or open fist properly. Specific comments were put forward on the game of bowling being really engaging and fun, but at the same time annoying since the ball did not reflect the movements properly. There were few comments regarding the restrained setup that seemed to be really tough or inconvenient. However, when explanations were given about the post-stroke rehabilitation usage, the participants agreed with the method and even said it would be really helpful for such patients.

Two Psychology experts reviewed the system during the user study and provided few insightful comments. If a person is really good in a game, say bowling, one would expect to score and perform better. But, the camera tracking is not as fast as real world and so it was difficult to track fast movements of a player, leading to bad performance. To add to that, if the enhancement mode is turned on, performance would even deteriorate, since it is counter-intuitive for the long trained muscles to slow down in compensation to the enhancement added. Enhancement made sense in the restrictive mode, where the muscles are forced to slow down, as shown in Figure 12, leading to improved performance. The experts concluded that enhancement would be really helpful for post-stroke patients since they have inherent restrictive motion. The concept of using cognitive aspect with exercise was really appreciated as well. A user study comparing the use of live 3D models vs 3D avatars was proposed by the psychology expert and is currently being set up.

The two Physical Medicine and Rehab experts based their analyses on the direct usage of the system with real patients with stroke. Even though the exergames were intuitive for stroke patients, they may have varying degrees of difficulty with the activity depending on the type of stroke and degree of physical impairment. Thus, the acceptability might not only depend on the patient's preferences, but also on the severity of stroke and the corresponding level of impairment. Given that stroke patients are a heterogeneous group, it is difficult to extrapolate information from this study on able-bodied individuals and apply it to patients after stroke. They feel that this type of inter-disciplinary innovative system with customizable games is ripe for further evaluation with post-stroke patient populations.

Some of the discouraging factors included the showing up of artifacts, for instance, due to fast sudden arm movements resulting in improper mesh prediction leading to degradation of visual quality in the virtual enhancement mode. Also, the open-close fist detection had false positives and negatives leading to confusion during the games. Other than these issues, almost everyone felt that the games created a fun, engaging and motivating environment for performing in-home exercises.

A video showcasing the exergames is available at :
https://www.youtube.com/watch?v=vPnOmuHkgVU

7. CONCLUSION & FUTURE WORK

The entire system is built with a focus on exergames for rehabilitation. The proposed exergame toolkit creates an immersive and mirrored augmented environment for performing exercise while playing a game. A positive reinforcement is provided with the use of mirror therapy and virtual enhancement on the live 3D model. The games turn out to be fun, engaging and at the same time motivating enough to play again and hence perform repetitive exercise on affected limbs. The setup is affordable, easy to use and suitable for in-home rehabilitation due to the fact that it requires only one computer, a TV and a Kinect camera.

In terms of improving the proposed games, we plan to improve the close and open fist detection algorithm provided by Kinect. We also plan to improve the animation based virtual enhancement as well as the mesh prediction strategy to get rid of the artifacts, especially during fast movements and self-occlusions. There are other body parts that can be exercised by playing different virtual games, thus increasing the versatility of the toolkit even more. Based on the inputs from Psychology experts, a detailed study is being planned to compare the use of virtual 3D avatar vs. live 3D human models. Given our preliminary positive findings for the usability and satisfaction with our system, we are pursuing research along with the rehab experts to evaluate the feasibility and effectiveness in stroke patient populations. According to rehab experts, this technology holds great promise and has potential to improve in-home rehab in several vulnerable populations, including patients affected with stroke as well as with chronic degenerative musculoskeletal pain conditions.

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